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PHOXES - MODULAR ELECTRONIC MUSIC INSTRUMENTS BASED ON PHYSICAL MODELING SOUND SYNTHESIS

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ABSTRACT

This paper describes the development of a set of electronic music instruments (PHOXES), which are based on physical modeling sound synthesis. The instruments are modular, meaning that they can be combined with each other in various ways in order to create richer systems, challenging both the control and perception, and thereby also the sonic potential of the models. A method for evaluating the PHOXES has been explored in the form of a pre-test where a test subject borrowed the instrument for a period of 10 days. The longer test period makes way for a more nuanced qualitative evaluation of how such instruments might be integrated into workflows of real world users.

1. INTRODUCTION

The PHOXES (Physical Boxes) are a set of musical instruments, which are based on physical modeling sound synthesis. They were developed in order to investigate how high level exploratory control structures have an impact on the sonic potential of physical models.

1.1 Exploring Physical Modeling

Traditionally the goal when developing physical models has been to accurately simulate the physical mechanisms, which produce sound in the real world. When controlling these models the goal has often been to achieve the same nuanced input capabilities as one would have when playing real acoustic instruments striving for an enhanced expressivity or intimacy.

This research deals with the ongoing investigation into how control structures for physical modeling sound synthesis, can enhance the explorability and thereby the creative potential of the technique. One goal is to understand how physical modeling can be controlled in order to accommodate the work processes of the end user (for us the experimental electronic musician). The focus is not on expressivity or intimacy of musical controllers, but on enhancing their exploratory and creative potential (note that these are not apposed to each other as a higher level of intimacy can also lead to a higher degree of exploration [1]).

Figure 1. The PHOXES system is modular and currently implements four different modules each implementing a different physical model and a different excitation controller. *Upper from left: friction PHOX and particle PHOX. Lower from left: drum PHOX and tube PHOX.*

We believe that physical modeling bears with it an obvious potential to maintain the balance between intuitive control and that certain amount of complexity that is needed in order facilitate the exploratory processes, which are so important for supporting creativity. Within creativity support tools research this balance is referred to as *Low threshold, high ceiling, and wide walls* [2].

One way of creating a low threshold can be to design input devices, which are built upon traditional acoustic instruments. Controls will not only be familiar, there will also be a great amount of users, who have already spent years on refining expert playing techniques. In developing the PHOXES we have worked in the opposite direction by leveraging on input devices and control structures found in commercial electronic music instruments, merging them with alternate input devices specifically suited towards the physical models.

2. PHOXES

Each PHOX is an instrument on its own implementing a physical model, an excitation controller and four knobs for adjusting various model parameters (mostly resonator parameters). The excitation controller lets the user inject energy into the physical model by performing musical gestures, which intuitively relate to that model. For instance the tube PHOX implements a flute controller for exciting a turbulence model. The user receives visual feedback in the form of exact control values on an LCD screen mounted on each PHOX.

Each PHOX works as a musical instrument on its own, but the PHOXES are modular, meaning that two or more PHOXES can be combined in various ways to produce sonically richer systems. Although each physical model is still fixed this lets the user explore the models in a totally different and more abstract way. Each PHOX still upholds an intuitive perception of how the sound is produced, because of the perceived causality inherent in the physical modeling technique. But when they are combined this perceived causality is challenged, altering both the gesture space provided by the PHOXES and the sonic potential of the models. How this is handled is described later in Section 2.5.

The goal when developing the PHOXES was to create a flexible system that while keeping each physical model fixed (not letting the user assemble their own physical model as seen in for example [3]), the users are able to combine the different models in various ways thereby achieving a different exploration of the sonic possibilities made available by each model. This section will describe the design and implementation of the PHOXES - in particular the physical models used, the choice of control devices (including how they were built) and the mapping strategies for developing the modular system.

2.1 Physical Models

Each of the individual PHOXES implements a different physical model, each representing a different physical modeling technique. They vary in complexity, sonic fidelity and physicality (which type of excitation gesture they naturally propose). The four PHOXES (as seen in Figure 1) and the physical models on which they are based are:

- **tube PHOX** - implements a *turbulence model* with a simple nonlinear exciter [4] and a one-dimensional waveguide resonator [5].
- **particle PHOX** - implements a *particle model* with a stochastic excitation based on Physically Informed Sonic Modeling (PhISM) by Perry Cook [6].
- **friction PHOX** - implements a *friction model* with a complex nonlinear exciter [7] and a one-dimensional waveguide resonator.
- **drum PHOX** - implements two identical *drum models* each with a simple nonlinear exciter and a two-dimensional waveguide resonator [8].

2.2 Physical Devices

As described in Section 1.1 the PHOXES have been inspired by commercial electronic music instruments. It was important that the eventual test environment was as natural for the test subjects as possible, which is also why the PHOXES were designed with a look and feel that were convincing enough to resemble real commercial hardware synthesizers. The PHOXES could have been presented

Figure 2. The flute controller is implemented using an amplified low pressure sensor mounted to the end of a tube, which the user blows into.

(and perhaps partially controlled) in a software environment, but it was important for us to put emphasis on the physical devices as standalone instruments - even though they are not. Finally, it was crucial that they were robust and durable enough to make a long term evaluation possible.

Each of the four PHOXES is implemented using a PhidgetTextLCD with PhidgetInterfaceKit 8/8/8 [1], which provides 8 analog inputs, 8 digital inputs, 8 digital outputs, and a 2-line by 20-character LCD screen. This makes it possible to control mapping settings, control settings, and display settings in a customized menu system directly on each of the instruments. The instruments connect to the computer via USB and communication, sound synthesis and mapping is handled directly from Max/MSP. The system has been tested on a MacBook Pro with 2.4 GHz Intel Core 2 Duo processor and 4GB 667 MHz DDR2 SDRAM - Mac OSX 10.5.8.

2.3 Excitation Controllers

Each PHOX implements a different excitation controller, which naturally relates to the physical model of that PHOX. The excitation controllers are as follows:

2.3.1 *tube PHOX Excitation Control - Flute*

The tube PHOX implements a flute controller, which by default controls the turbulence model. The flute controller implements an amplified low pressure sensor [2], which is attached to a tube that the user blows into - see Figure 2. The pressure sensor is very responsive and is sensitive enough for detecting very small differences in air pressure produced by the blowing gesture and because the signal is amplified it connects directly into the Phidget interface [3]. The air pressure is mapped to the input energy into the physical model.

2.3.2 *particle PHOX Excitation Control - Crank*

The particle PHOX implements a crank as its default excitation controller - see Figure 3. The crank is attached to a

[1] from http://phidgets.com
[2] the 1INCH-D-4V from All Sensors
[3] could also be an Arduino or CUI interface or the likes

Figure 3. The crank is used as excitation controller for the particle PHOX. It is attached to a multi-turn rotational potentiometer.

Figure 4. The friction PHOX implements a ribbon sensor, which lets the user slide his or finger back and forth over the surface to create energy.

multi-turn rotational potentiometer [4] and the rotational velocity of the potentiometer is mapped to the input energy of the physical model - the probability of a particle hit in the case of the particle PHOX.

2.3.3 *friction PHOX Excitation Control - Slide Surface*

The friction excitation controller is implemented using a ribbon sensor (a soft potentiometer [5]) - see Figure 4. The user slides his or her finger back and forth on the surface to create energy. The velocity of the motion is mapped to the input energy of the physical model.

2.3.4 *drum PHOX Excitation Control - Drum Triggers*

The excitation controller for the drum PHOX consists of two drum triggers built from piezo transducers [6] - see Figure 5. The transducer produces a voltage when struck - this is thresholded to detect a hit and peak detected to determine the velocity of the hit.

2.4 Model Parameter Controls

Each PHOX also implements four knobs, which let the users control selected parameters of the physical model. For instance one is able to adjust how long the tube is, or how dampened the particles collide. Physically, they are controlled by simple knobs (potentiometers), which help establish the look of the PHOXES by aesthetically connecting them to more traditional electronic instruments or controllers. They present a familiar control surface, which lowers the threshold for electronic musicians initially learning the instruments and finally, because they are the same on each PHOX, they help to perceptually connect the different PHOXES into one system.

[4] Model 357 from Vishay
[5] SoftPot from Spectra Symbol
[6] KPSG100 from Kingstate

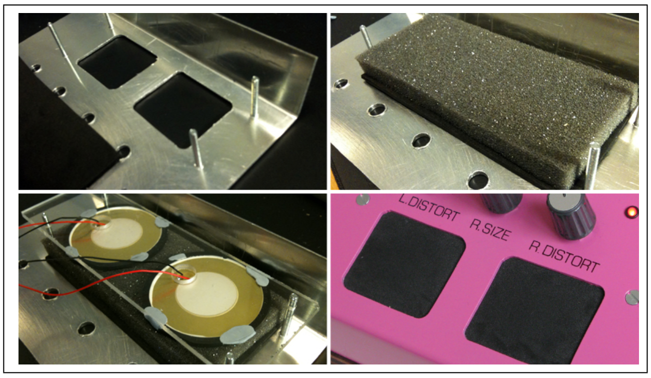

Figure 5. The drum PHOX implements two drum triggers, which were implemented by mounting two piezoelectric discs under two layers of foam.

The following is an overview of which model parameters are controllable. Parameters for the tube PHOX are *tube length 1, tube length 2, vibrato*, and *flute airyness).* Parameters for the particle PHOX are *fundamental frequency, approximate frequency of four partials, amount of randomization of partial frequencies*, and *bandwidth of the partials*. Parameters for the friction PHOX are *frequency 1, frequency 2, downward force*, and *roughness (randomness of force and amount of noise)*. Finally, parameters for the drum PHOX are *left drum size, left drum frequency distortion, right drum size*, and *right drum frequency distortion*.

2.5 Modularity

2.5.1 *Exploration of excitation gestures*

By default each PHOX has a dedicated controller, which is intended to presents a natural intuitive relationship between excitation gesture and model. This helps the user to get a first intuitive impression of the model's control possibilities. However, the user can also choose to control the physical model using the excitation controller imbedded in any of the other PHOXES. For instance instead of exciting the friction model of the friction PHOX using the *slide surface* one is able to use the *crank*. This lets the user explore different playing styles by performing different excitation gestures - thereby hopefully achieving a deeper exploration of the sonic potential of the physical models.

The flexibility of the PHOXES system entails an implementation challenge because each PHOX must uphold a meaningful relationship between input gesture and the sound being produced no matter what type of excitation gesture. The idea is to use *energy* as the common denominator as each model relies on energy in order to be excited. But how that energy mechanically relates to each model must be defined. The challenge becomes particularly interesting when shifting between continuous excitation gestures (e.g. blowing into the flute controller) and instantaneous excitation gestures (e.g. tapping/striking the drum trigger). A number of different possible mapping solutions were considered, but we chose to map the energy of a drum hit to an energy envelope, which has a peak proportional to the hit velocity and which decays in energy again proportional to the hit velocity (linear decay lasting between 200 and 500 ms.). This means that when using the drum triggers to excite for instance the turbulence model, the amount of air pressure (exciting the turbulence model) will be enveloped according to the hit velocity of the drum.

For mapping a continuous gesture (e.g. rotating the crank) to a model that normally is excited by instantaneous gestures (tapping/striking the drum trigger) a similar challenge occurs. We have chosen to let the instantaneous gesture take shape as a scraping mechanism, which creates small instantaneous excitations we can use for exciting the drum. How frequent the excitations occur and their individual velocities depend on the velocity of the continuous gesture.

2.5.2 *Controlling one physical model with another*

Energy into the physical model of a PHOX need not come from an excitation controller. The system makes it possible for the user to drive the physical model using the output sound from a different model - similar to [9]. This means that for instance the turbulence model, which by default is excited with a certain amount of white noise (proportional to how hard the user blows), can be excited by the output sound from e.g. the drum model. This is done by substituting the white noise with the audio output from the drum model. It thus becomes the drum sound, which drives the turbulence model. The result is a sort of fusion between the two models, where the turbulence model acts as a sort of audio effect, which is used to color the drum sound.

Earlier research has shown that interesting timbres from one model can be transferred to another model, and models, which users rate as boring can become interesting when combined in this fashion with other models - (even with each other) [10]. The PHOXES extend this idea by making it possible to combine many models at the same time (for instance use the crank of the particle PHOX to excite the turbulence model of the tube PHOX then letting the resulting audio signal excite the friction PHOX and so on and so forth).

Because the user is able to excite one PHOX with audio output from a different PHOX, each model must have a way of taking audio as input and somehow substituting that with the energy input of the model.

For complete details regarding mapping go to `http://media.aau.dk/~stg/phoxes/`.

3. PRE-TEST

In order to explore a suitable method for evaluating the PHOXES a pre-test was conducted. Carrying out any formal evaluation of these kinds of instrumental systems in the rather complex environment of creative music making has proven to be quite challenging. Different evaluation methods have been proposed for evaluation of musical interfaces inspired by methodologies found in the field of Human Computer Interaction (HCI) [11, 12]. For this pre-test we wanted to explore methodologies related not so much to the performance or usability of the system (how well the user is able to perform specific tasks) but more the overall experience with the system dealing with softer hedonic qualities [13, 14, 15] - for instance how well the user identifies with the instruments, whether they are inspiring to work with or how well the system supports musical exploration.

Most formal evaluations of musical interfaces are carried out under circumstances far from the natural environment of the electronic musician, which may be adequate for various specific usability issues [16]. But we believe that this makes it difficult to evaluate factors of more qualitative nature. Earlier research [17] has also suggested that tests need to be carried out over longer periods of time, which is especially enforced when evaluating more complex systems.

The pre-test was carried out using one male test person who is an experienced experimental electronic musician. He has extensive experience with both traditional acoustic instruments (mostly percussion instruments) and with various electronic instruments as both a composer and a performer. The test took place over a period of 10 days where the test-subject borrowed the PHOXES. The test was very free as the test person did not receive any instruction as to any specific tasks to perform during the 10 days. The test subject was instructed to treat the instruments as he would any new musical device that came into his possession.

In order to asses the implications of the longer test period, first impressions were noted by having the test subject fill in a questionnaire after having played around with the PHOXES for approximately one hour. The questionnaire was comprised of two forms: One was the AttrakDiff [7] hedonic / pragmatic evaluation form also used in [13], which lets the user rate the system based on a series of opposite/bipolar word-pairs relating to hedonistic and pragmatic qualities of interactive systems. The other was a semi-quantitative Likert-scale style evaluation form that lets the user rate each individual PHOX and the overall system in regards to features more closely related to the specific area of physical modeling based electronic instruments - such as whether the instruments provided sonic diversity, or felt like a real acoustic instrument. The same questionnaire was filled out after the 10 days test period. Finally an open interview was conducted to gather qualitative statements about how the test-subject worked with the PHOXES, whether that changed throughout the test-period and which issues arose during the test-period.

4. RESULTS AND DISCUSSION

The main focus when evaluating the data collected in the pre-test was on the methodological approach, and specifically on what kind of system improvements have to be made if this kind of evaluation method is to succeed on a greater scale. However, the results of the evaluation have been included to provide an initial idea of the perceived qualities of the PHOXES system. Note that they are totally subjective and inconclusive as only one test subject participated in the test.

The results indicate that the test subject was highly motivated and stimulated by the PHOXES system (Hedonic Quality - Stimulation) and found them having a high per-

[7] http://www.attrakdiff.de

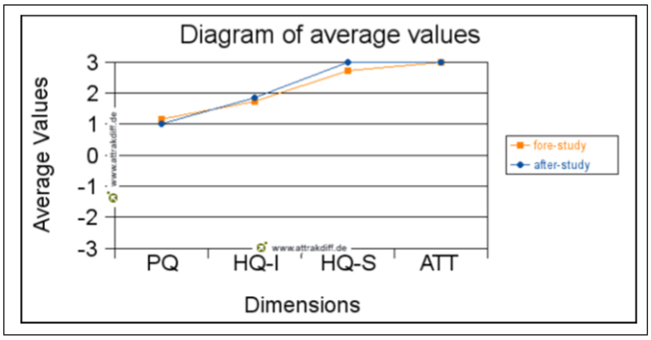

Figure 6. Results of the AttrakDiff evaluation. The following dimensions are evaluated: Pragmatic Quality (PQ), Hedonic Quality - Identity (HQ-I), Hedonic Quality - Stimulation (HQ-S) and Attractiveness (ATT). Fore study corresponds to first impressions and after study corresponds to the final evaluation.

ceived quality (Attractiveness). The subject's identification with the system was above average (Hedonic Quality - Identity) - as so was the perceived usability (Pragmatic Quality).

Surprisingly the perceived hedonic and pragmatic qualities stayed more or less unaltered when comparing answers from the first impressions evaluation and the final evaluation after the 10 days - See Figure 6.

Problems with the PHOXES in regards to the relatively uncontrollable test scenario were found in the computational cost of the physical models. The DSP CPU load would limit the test subject as he integrated the PHOXES into larger sequences/multitrack recordings in his preferred digital audio workstation (Ableton Live). This was quite unfortunate, as it is important for us to examine how the PHOXES are able to integrate into the work flow of eventual future test subjects in order to evaluate their exploratory qualities. Apart from cleaning up the code (Max/MSP patch and externals) making it run more smoothly, a solution could be to keep the processing on a separate dedicated machine. On the positive side, the physical interfaces were easy to setup and physically durable enough for the 10 days test period.

There was a problem that the test subject did not get to explore parts of the modular system. As the test subject put it; he didn't get to the advanced settings. It is difficult to say whether the system was too complicated, whether the system was not presented intuitively enough, or whether the test period might have been too short. The subject might also have been too focussed on improving playing skills, focussing on the interplay between controllers and models, and not so much on the combining of models. On one hand more time or explicit tasks could be given to the participants in order to get them to focus on certain parts of the system. On the other hand it is valuable to see how different uses of the system might arise by absence of specific tasks.

We were pleased to experience that the PHOXES system was robust enough to handle 10 days of use without our interference. For future testing we will improve the PHOXES in accordance with the improvements described above. We will continue to explore the methodological approach, including a longer test period and more task oriented restrictions to parts of the evaluation period.

5. REFERENCES

[1] D. Wessel and M. Wright, "Problems and prospects for intimate musical control of computers," *Computer Music Journal*, vol. 26, no. 3, pp. 11–22, 2002.

[2] B. Shneiderman, G. Fischer, M. Czerwinski, M. Resnick, B. A. Myers, L. Candy, E. A. Edmonds, M. Eisenberg, E. Giaccardi, T. T. Hewett, P. Jennings, B. Kules, K. Nakakoji, J. F. Nunamaker, R. F. Pausch, T. Selker, E. Sylvan, and M. A. Terry, "Creativity support tools: Report from a u.s. national science foundation sponsored workshop," *International Journal of Human Computer Interaction*, vol. 20, no. 2, pp. 61–77, 2006.

[3] C. Cadoz, A. Luciani, and J. L. Florens, "Cordis-anima: A modelling and simulation system for sound and image synthesis — the general formalism," *Computer Music Journal*, vol. 17, no. 1, 1993.

[4] P. Cook, "A meta-wind-instrument physical model, and a meta-controller for real time performance control," in *Proceedings of the International Computer Music Conference*, pp. 273–276, San Francisco, California: International Computer Music Association, 1992.

[5] J. O. Smith, *Physical Audio Signal Processing, December 2008 Edition*. http://-ccrma.stanford.edu/~jos/-pasp/Digital_Waveguide_Models.html, 2008. online book.

[6] P. R. Cook, "Physically informed sonic modeling (phism): Synthesis of percussive sounds," *Computer Music Journal*, vol. 21, no. 3, pp. 38–49, 1997.

[7] F. Avanzini, S. Serafin, and D. Rocchesso, "Modeling interactions between rubbed dry surfaces using an elasto-plastic friction model," in *Proceedings of the International Conference on Digital Audio Effects*, (Hamburg), pp. 111–116, DAFX, 2002.

[8] S. A. V. Duyne and J. O. Smith, "Physical modeling with the 2-d digital waveguide mesh," in *Proceedings of the International Computer Music Conference*, pp. 40–47, San Francisco, California: International Computer Music Association, 1993.

[9] S. Gelineck and S. Serafin, "A practical approach towards an exploratory framework for physical modeling," *Computer Music Journal*, vol. 34, no. 2, 2010.

[10] N. Böttcher, S. Gelineck, and S. Serafin, "Physmism: A control interface for creative exploration of physical models," in *Proceedings of the International Conference on New Interfaces for Musical Expression*, 2007.

[11] M. M. Wanderley and N. Orio, “Evaluation of input devices for musical expression: Borrowing tools from hci,” *Computer Music Journal*, vol. 26, no. 3, pp. 62–76, 2000.

[12] C. Kiefer, N. Collins, and G. Fitzpatrick, “Hci methodology for evaluating musical controllers: A case study,” in *Proceedings of NIME*, 2008.

[13] C. Geiger, H. Reckter, D. Paschke, F. Schutz, and C. Poepel, “Towards participatory design and evaluation of theremin-based musical interfaces,” in *Proceedings of the Conference on New Interfaces for Musical Expression*, 2008.

[14] M. Hassenzahl, A. Platz, M. Burmester, and K. Lehner, “Past, present, and future of user interface software tools,” *CHI Letters*, vol. 2, no. 1, pp. 201–208, 2000.

[15] D. Fallman and J. Waterworth, “Dealing with user experience and affective evaluation in hci design: A repertory grid approach,” in *CHI 2005, Conference on Human Factors in Computing Systems*, 2005.

[16] M. T. Marshall, M. Hartshorn, M. M. Wanderley, and D. J. Levitin, “Sensor choice for parameter modulations in digital musical instruments: Empirical evidence from pitch modulation,” *Journal of New Music Research*, vol. 38, no. 3, pp. 241–253, 2009.

[17] S. Gelineck and S. Serafin, “A quantitative evaluation of the differences between knobs and sliders,” in *Proceedings of the International Conference on New Interfaces for Musical Expression*, 2009.